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Computational Assessment of Damage Patterns and Stress-Strain Behavior for Dry-Stacked Block Masonry Under Quasistatic Loading

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ABSTRACT

As engineers, we are always in search of construction materials that are readily available, cost-effective, and, most importantly, durable. Due to these characteristics, masonry is widely used worldwide. However, traditional masonry has inherent limitations, such as low tensile strength, making it vulnerable to cracking under flexural and lateral loads. Additionally, masonry structures are brittle in nature, which limits their ability to withstand dynamic forces such as seismic and impact loads. Conventional masonry construction also requires more time and skilled labor, making it less efficient.

In such a situation, there is a need for construction materials that are durable enough to withstand earthquake loading, require less construction time, and reduce labor costs. One such material is Interlocking Block Masonry, which has shown significant improvements in seismic performance while remaining cost-effective.

As a developing nation, it is crucial to adopt advanced techniques that can predict structural responses without requiring physical construction. One such highly effective technique is Finite Element Modeling (FEM), which enables engineers to analyze and optimize structures through computational simulations. This approach saves time and resources while enhancing safety by identifying potential weaknesses before implementation.

The purpose of this research is to assess the lateral load resistance of Dry Stacked masonry walls under quasistatic loading using a micro-modeling approach. The numerical model is developed and analyzed in FEA software and validated against experimental quasistatic loading tests. The results of this study provide valuable insights into the lateral load-carrying capacity of interlocking block masonry, demonstrating its effectiveness as a seismic-resistant and economical construction solution.

Dry Stacked Masonry, Numerical Modelling, Lateral Load Resistance

1. Introduction:

Masonry construction has been an integral part of human civilization for centuries, providing durable and cost-effective solutions for buildings and infrastructure. It is widely used due to its abundant availability, ease of use, and relatively low construction costs. However, despite its numerous advantages, traditional masonry structures have inherent weaknesses that limit their performance, especially in seismic-prone regions.

One of the primary concerns associated with masonry construction is its low tensile strength, making it highly susceptible to cracking under flexural and lateral loads. The brittle nature of masonry materials often results in a lack of ductility, which reduces their ability to withstand dynamic forces such as seismic and impact loads. Furthermore, the construction process for conventional masonry is labor-intensive and time-consuming, requiring skilled masons to ensure structural integrity. These limitations highlight the need for alternative construction techniques that enhance efficiency, reduce construction time, and improve seismic resilience (Paulay & Priestley, 1992; Lourenço, 1996).

Interlocking block masonry has emerged as a viable alternative to traditional masonry due to its improved structural performance and ease of construction. This system eliminates the need for mortar, thereby reducing construction time and labor costs (Keya et al., 2017). Studies have demonstrated that interlocking masonry exhibits enhanced seismic resistance due to its ability to accommodate relative displacements without significant damage (Ramamurthy & Nambiar, 2004; Walker, 1999). Furthermore, experimental and numerical studies have shown that interlocking blocks provide better lateral load resistance compared to conventional brick masonry (Thanoon et al., 2004)

Masonry structures are particularly vulnerable to seismic forces due to their low tensile strength and brittle behavior. Research on unreinforced masonry (URM) buildings has highlighted their poor performance in past earthquakes (D'Ayala & Speranza, 2003). However, reinforced and interlocking masonry systems have demonstrated better energy dissipation and improved seismic resilience (Brzev, 2007). Quasi-static cyclic loading tests on masonry walls have provided insights into their lateral load-carrying capacity and failure mechanisms (Tomazevic, 1999).

1.1 Importance of Dry Stacked Masonry

The importance of dry stacked masonry lies in its cost-effectiveness, ease of assembly, and sustainability. By eliminating mortar, construction waste is reduced, and the need for skilled labor is minimized, making it an ideal solution for low-cost housing and emergency shelters. Additionally, interlocking dry stacked masonry provides improved seismic performance due to its ability to allow controlled movement and energy dissipation during an earthquake.

This technique is widely used in various applications, including residential buildings, retaining walls, and infrastructure projects. Its modularity and speed of construction make it a viable alternative to conventional masonry techniques, particularly in regions where rapid, cost-effective, and durable construction solutions are required.

1.2 Finite Element Analysis:

Finite Element Analysis (FEA) has proven to be a powerful tool for evaluating the structural response of masonry structures. Micro-modeling and macro-modeling approaches are commonly used to simulate masonry behavior, with micro-modeling providing more detailed insights into crack propagation and failure patterns (Lourenço et al., 2007). The Concrete Damage Plasticity (CDP) model has been widely used to simulate damage in masonry walls under lateral loads (Jafari et al., 2018). Validation of numerical models against experimental data is crucial for ensuring accuracy and reliability in predictive analysis (Ghiassi et al., 2016).

Various modelling approaches have been used to analyse the behaviour of masonry structures. The three modelling strategies suggested by Lourenco (1996) are micro-modelling, meso modelling, and macro-modelling. This author further added that meso modelling only deals with the interface bond strength between masonry units through mortar while the behaviour of mortar itself is not considered. Micro-modelling requires high computational efforts as the masonry units are modelled one by one, while macro-modelling is a homogeneous model and requires less computational efforts.

Micro-modelling of DSM wall was performed by using DIANA as an eight node continuum plane stress element, while joints are modelled as a six node and zero thickness line interface. The experimental and numerical behaviour matched for monotonic load while the same did not match for cyclic loading because of crack closure.

Ample research work has been carried out on the computational behaviour of conventional masonry, but little research work has been done, to analyse numerically, the in-plane behaviour of dry-stack masonry. Experimental research work gives an actual testing data and graphical representation of a structural behaviour but is time consuming, laborious and uneconomical. Therefore, this research work has been carried out to analyse the dry-stack block masonry walls for in-plane behaviour, using numerical strategy.

In this research work an analytical attempt has been made to model an unconfined/unreinforced DSM wall, using finite element package ABAQUS. The analytical results thus obtained have been compared with the experimental results to check the authentication of the numerical tool. The in-plane behaviour of dry-stacked masonry wall with precompression loading has been assessed numerically for principal stresses and strains, tensile and compression damages

Numerical Modelling of Model

For this Study geometry of the interlocking block masonry wall measuing 3048 × 3276 × 229 mm was created using CAD software based on experimental tests and data performed on Dry Stacked Masonry in the Structural Laboratory of University of Engineering and Technology Peshawar

Geometries for confining elements, such as RCC pad columns, were also defined individually. Each block was modeled as a separate solid part, incorporating interlocking features. The material properties were assigned based on experimental data or literature values, with the Concrete Damage Plasticity (CDP) model used to define the nonlinear behavior of the blocks. Parameters such as compressive strength, tensile strength, dilation angle, and damage parameters were specified.shown in Table 1,2 and 3.

Contact properties were defined to simulate the interaction between blocks. A surface-to-surface contact approach was employed, incorporating tangential friction and normal hard contact. The base of the wall was fixed to prevent movement and simulate real-life constraints.A Precompression load of 22Psi were applied to simulate actual filed condition, while seismic or lateral loading was applied based on research objectives using displacement-controlled or force-controlled methods. Static analysis steps were implemented based on the type of loading.

The model was analyzed using an implicit solver. Nonlinear effects such as cracking, crushing, and block separation were captured using the CDP model. The analysis was monitored for convergence, with stabilization techniques applied if needed. Results, including displacement, stress distribution, and damage patterns, were extracted. The model was validated by comparing simulation results with experimental data or previous studies. Sensitivity analysis was conducted to assess the influence of material properties and boundary conditions on structural behavior.

2.1 Material Properties

For the Non-linear Behavior Concrete Damage Plasticity Model is use, following tables shows the CDP Properties:

Table 1 -Plasticity Parameters:

Dilation Angle	Eccentricity	Fb0/fc0	k	Viscosity Parameter
38	0.1	1.16	0.6667	0.0005

Table 2: Compressive Behavior

Concrete Compression Damage	
Compressive Behavior	
Yield Stress	**Inelastic Properties**
7.6	0
16.7	0.000376
19	0.001008
19	0.002748
Compression Damage	
Damage Parameter, dc	**Inelastic Strain**
0	0
0.13051	0.000376
0.303791	0.001008
0.5	0.002748

Table 3: Tensile Behavior

Concrete Tension Damage	
Tension Behavior	
Yield Stress	**Crushing Strain**
1.5	0
0.9869	0.010945
0.015	0.1204
Tension Damage	
Damage Parameter	**Cracking Strain**
0	0
0.24	0.010945
0.3	0.1204

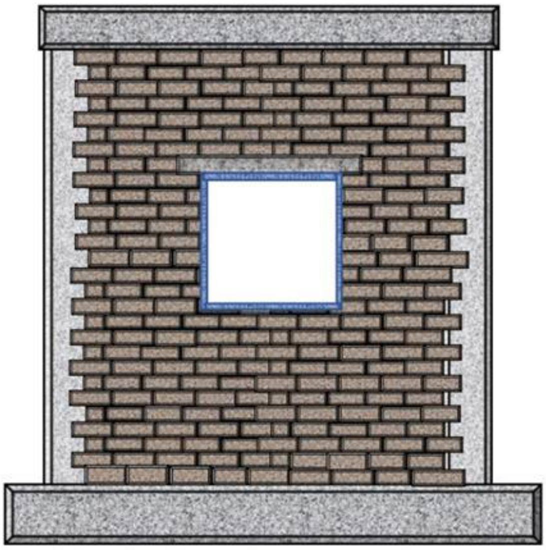

Fig. 1 Experimental Model

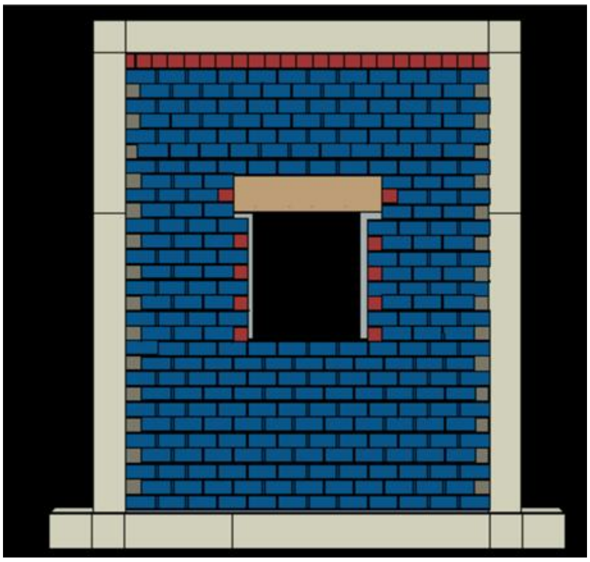

Fig. 2 Numerical Model

3. Results and Discussion:

The specimen with window opening (WW) was examined under Quasistatic loading condition, from experimental Study it was concluded that first crack appeared at a drift of 0.19% which increased with increase in displacement, While in Numerical Study first Crack appear at a Drift of 0.17% at Pivot Point where Quasistatic loading assembly is attached for application of load show in Figure 03.

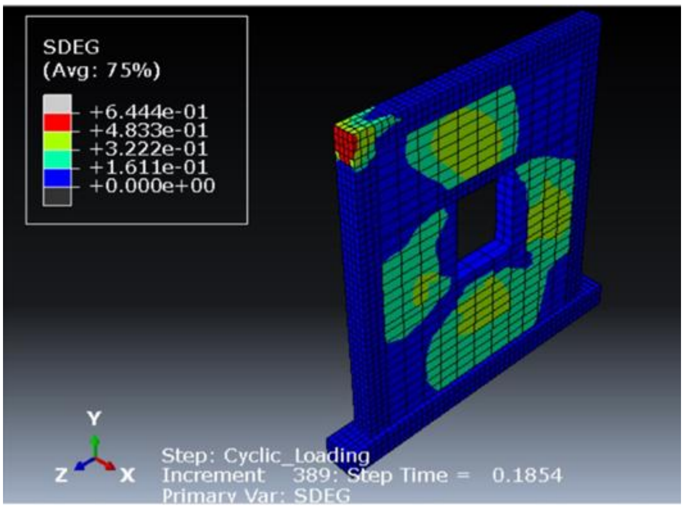

Fig. 3 First Crack appearance at 0.17% Drift

After that at a Drift of 0.21% Cracks start/appear at top most layers of IBM above the Plinth beam of window frame and increases further in IBM layers reaches the Bottom pad and Confining elements that were also observe in Experimental study .shown in Figure 04

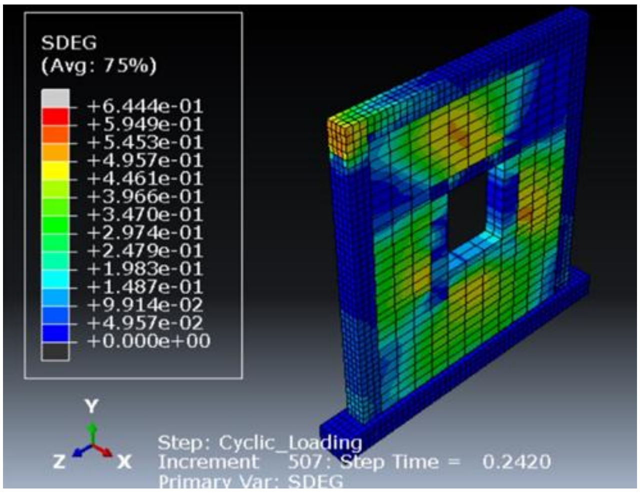

Fig. 4 Damage pattern at 0.21% Drift

The connection between window steel frame and blocks failed at a drift of 0.32% in Experimental Study while in Numerical study Major cracks near the Steel frame were observed at a Drift of 0.43%. At further high drift, some blocks completely crushed and opening gap of 12.7 mm was also noted. Overall, the WW specimen showed a diverse shear-flexural failure pattern .

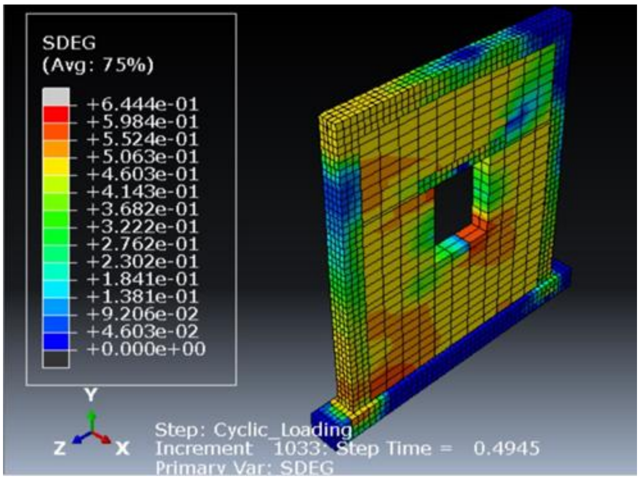

Fig. 5 Damage Pattern at 0.43% Drift

Stress-Strain Contours are Visualize through Visualization Module after the Analysis is completed. Stress in X-direction(S22),Stress in Z-Direction(S33).

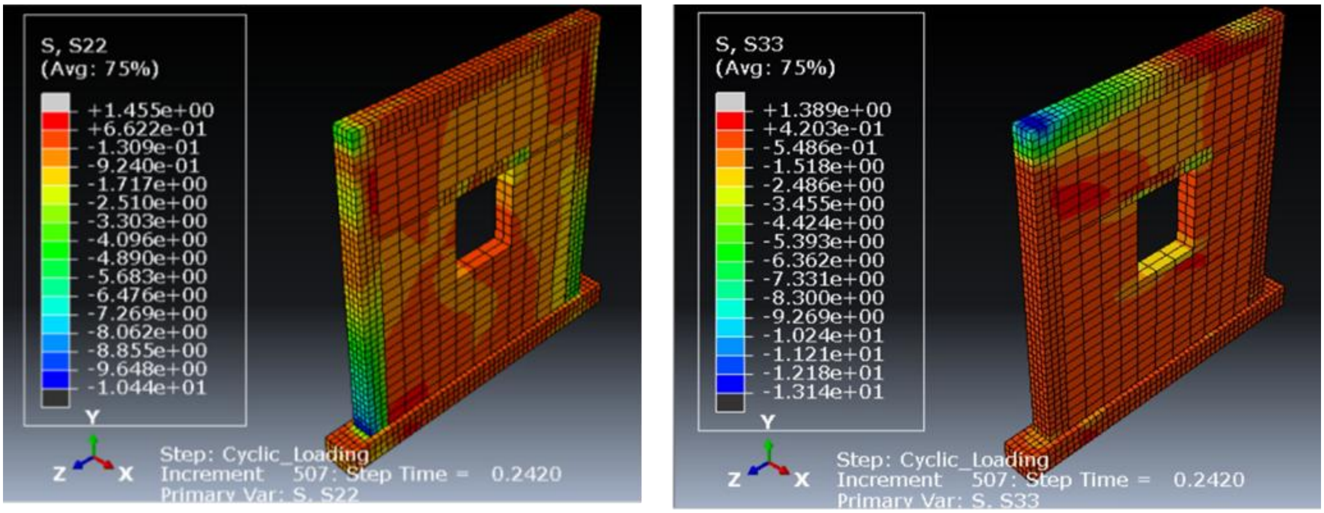

Fig. 6 (a) Stress S22 Contours (b) Stress S33 Contours

4. Conclusion

- The first crack appeared at a drift of 0.19% in the experimental study, while in the numerical study, it was observed slightly earlier at 0.17% at the pivot point where the quasistatic loading assembly was attached.
- As the displacement increased, cracks started forming at a drift of 0.21% in the topmost interlocking block masonry (IBM) layers above the plinth beam of the window frame and propagated downwards, consistent with experimental observations.
- The connection between the window steel frame and masonry blocks failed at a drift of 0.32% in the experimental study, whereas major cracks near the steel frame were observed at a drift of 0.43% in the numerical analysis.
- At higher drift levels, some blocks experienced complete crushing, and an opening gap of 12.7 mm was recorded. The WW specimen exhibited a combined shear-flexural failure pattern under quasistatic loading.
- Stress-strain contours were visualized through the Visualization Module, showing stress concentrations in the X-direction (S22) and Z-direction (S33).
- The numerical results closely followed experimental trends, validating the modeling approach and capturing the nonlinear seismic behavior of interlocking block masonry with window openings.

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